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STEEL FOR MACHINE STRUCTURAL USE HAVING EXCELLENT CHIP BREAKABILITY

Technical Field

The present invention concerns a steel for machine structural use having excellent chip-breakability at machining with cemented carbide tools. The steel for machine structural use of the invention is characterized by configuration of sulfide inclusions in the steel.

In the specification the term "Ca-containing sulfide inclusion" means the inclusion of the structure formed by a core inclusion mainly consisting of CaO, and another inclusion mainly consisting of sulfides and surrounding the core. In regard to the MnS inclusion the phrase "finely dispersed" means that the inclusion particles are finer than the MnS inclusion particles in the conventional steel, and that they are homogeneously dispersed throughout the steel without either coagulation or concentration. The "aspect ratio" is defined as the value given by dividing the longest diameter by the shortest diameter of the inclusion particles observed on the surface formed by cutting a steel sample along the direction of rolling.

Background Technology

Research for developing machine structural steel with good machinability has been made for years, and as the

results, steels containing various machinability-improving elements have been proposed. They are sulfur free cutting steel, tellurium free cutting steel, calcium free cutting steel, lead free cutting steel and sulfur-calcium free cutting steel. Of these steels, lead free cutting steel is superb in that it has improved machinability without substantial lowering of mechanical properties of the steel. Recently, however, due to increasing significance of environmental problems, free cutting steels containing no lead are often demanded.

The technical problem common in the lead-free free cutting steels is breakability of chips at machining. As is well known, in the automated machining not only tool lives but also the chip breakability is important, because lower chip breakability may cause entangling of the chips with the tools or works, or conveying troubles in chip conveyers, and thus, results in obstruction of automation. With the premise that enjoying the excellent chip breakability of lead free cutting steel is given up, it is necessary to improve the chip breakability of the sulfur free cutting steels or sulfur-calcium free cutting steels, which are the majors of lead-free free cutting steels.

Efforts have been made to realize improved chip breakability by controlling the aspect or configuration of sulfide-based inclusion particles which bear the machinability. At present, however, the achieved chip breakability is not satisfactory, because the fluctuation of

the improvement is significant and it is difficult to ensured substantially constant chip breakability.

The applicants have been made research in this technical field. Our discovery mentioned above that the structure of the inclusion particles consisting of the core of CaO-containing inclusion and the surrounding sulfide inclusion is useful is one of the results of our research activities.

The recent knowledge on improving the chip breakability and ensuring a certain level of the effect, in addition to the increase of tool lives, by controlling the configuration of the sulfide inclusion particles is that it is necessary to form numerous fine sulfide inclusion particles for realizing good chip breakability. More specifically, it is necessary to satisfy the condition that at least five MnS inclusion particles having averaged size of 1.0μm or more exist per S-content 0.01%.

However, it was further discovered that existence of fine sulfide inclusion particles is not sufficient and that it is necessary to form sulfide inclusion films having a smaller friction coefficient with the chips on the surface of the tools. The mechanism is explained as follows. If the sulfide films of smaller friction coefficient with the chips are formed on the surfaces of the tools, the films give the effect of decreasing "curl diameter" of the chips formed by machining, and as the results, the chips may be easily broken. It is discovered that such a sulfide film

may be formed only in the cases where the Ca-containing sulfide inclusion having specific configuration occupies a specific quantitative range in all the sulfide inclusions.

Disclosure of the Invention

The object of the invention is to provide, on the basis of the above mentioned our discovery, a free cutting steel for machine structural use which facilitates automation of machining by controlling the configuration of the sulfide inclusion particles so that the good tool lives and improved chip breakability may be enjoyed.

The steel for machine structural use having excellent chip breakability of the present invention which achieves the above mentioned object is a steel containing alloying elements necessary for a steel for machine structural use, without either Pb or Bi, and in the steel, at least five MnS inclusion particles having averaged particles sizes of 1.0 μm or more exists per mm^2 per S-content 0.01%, the condition that, in the microscopic fields, (area[μm^2]/aspect ratio) $\geq$ 10 is satisfied, and that the area percentage of Ca-containing sulfide inclusion particles containing at least 1.0wt.% of Ca is in the range of 15-40% of the area of all the sulfide inclusion particles.

A typical steel containing alloy elements necessary for a steel for machine structural use consists essentially of, by wt.%, C: 0.05-0.8%, Si: 0.01-2.5%, Mn: 0.1-3.5%, S: 0.01-0.2%, Ca alone or both Ca and Mg (in case of the both

is used, the total amount): 0.0005-0.02%, one or both of Ti: 0.002-0.010% and Zr: 0.002-0.025%, and O: 0.0005-0.010%, and the balance of inevitable impurities and Fe.

The Best Mode for Practicing the Invention

The following explains the reason for choosing the alloy components and limiting the composition of the typical steel for machine structural use of the invention as mentioned above.

C: 0.05-0.8%

Carbon is necessary for ensuring strength of the steel, and a C-content less than 0.05% will not give the sufficient strength to the steel for the machine structural use. On the other hand, carbon increases the activity of sulfur, and, at a higher C-content, it will be difficult to form the Ca-containing sulfide inclusion. At the same time, a larger amount of carbon lowers the resilience and the machinability of the steel. Thus, the upper limit is set to 0.8%.

Si: 0.01-2.5%

Silicon is used as a deoxidizing agent at steelmaking and becomes a component of the steel. Si is useful because it enhances hardenability of the steel. The effect may not be expected at a small amount less than 0.01%. Si also increases the activity of sulfur, and a large amount of Si causes the same problem as that of a large amount of carbon, namely, formation of Ca-containing sulfide inclusion may be

prevented. Also, a large amount of Si damages the resilience of the steel, which results in tendency of cracking at plastic processing. The addition amount of Si must be, therefore, up to 2.5%.

Mn: 0.1-3.5%

Manganese is an important element for forming the sulfide. Unless the Mn-content in the steel does not reach 0.1%, the amount of the formed inclusion will be insufficient. Excess addition of Mn more than 3.5% makes the steel hard and lowers the machinability.

S: 0.01-0.2%

Sulfur is an essential element for forming the sulfides, and added in an amount of 0.01% or more. For the purpose of achieving the "tool life ratio" of 5 or more aimed at by the invention sulfur of 0.01% or more is necessary. An S-content higher than 0.2% not only damages both the resilience and the ductility of the steel but also causes combination of S and Ca to form CaS. CaS will cause troubles in casting due to its high melting point.

Ca alone or both Ca and Mg (in case of the both is used, the total amount): 0.0005-0.02%

Calcium is a very important component for the present steel. In order to have Ca contained in the sulfide inclusion it is essential to add Ca amounting to 0.0005% or more. On the other hand, too much addition of Ca exceeding 0.02% brings about formation of the above mentioned high melting point CaS, which causes troubles in casting. It is

possible to replace a part of Ca with Mg. In that case, however, it is preferable that the Ca-content may not fall below the above mentioned lower limit, 0.0005%.

One or both of Ti: 0.002-0.010% and Zr: 0.002-0.025%

A small amount of titanium or zirconium combines with oxygen in the steel which was deoxidized with calcium and aluminum to form finely divided oxides. The oxide inclusion particles act as the cores at precipitation of MnS, and are useful for the fine dispersion of the MnS inclusion particles. It is advantageous to use both Ti and Zr, because the fine dispersing effect on MnS will be stronger. In order to form suitable amounts of Ti-oxide and Zr-oxide it is necessary to control the addition amounts of Ti an Zr to be in the above ranges, i.e., 0.002-0.010% and 0.002-0.025%.

O: 0.0005-0.010%

Oxygen is an element essential for forming oxides. Because a large amount of CaS forms in an excessively deoxidized steel and causes troubles in casting, at least 0.0005% of oxygen is necessary, and 0.0015% or more is preferable. Oxygen of a content exceeding 0.01% will give a large amount of hard oxides, and as the results, the machinability will be damaged and formation of the desired Ca-containing sulfide inclusion will be difficult.

Phosphor, which is inevitable as an impurity in the steel, is halmful to the resilience, and therefore, should not be contained in an amount exceeding 0.2%. However, P is

a component which improves the machinability, particularly, the properties of the finished surface. This effect may be observed at a content of 0.001% or more.

The free cutting steel for machine structural use may optionally contain, in addition to the above mentioned basic alloying components, depending on the use of the steel, one or more of the elements of the following groups in the ranges defined below. The following explains the roles of the optional alloying elements and the reasons for limiting the composition ranges in the modified embodiments of the invention.

One or more of Se: up to 0.4%, Te: up to 0.2% and REM: up to 0.05%

These elements are machinability-improving elements. The respective upper limits, 0.4%, 0.2% and 0.05% were set in consideration of unfavorable effect on the hot workability of the steel and prevention of forming the fine sulfide inclusion partioles by excess addition.

One or more of Cr: up to 3.5%, Mo: up to 2.0%, Cu: up to 2.0%, Ni: up to 4.0% and B: 0.0005-0.01%

Chromium and molybdenum enhance hardenability of the steel and addition of a suitable amount or amounts are recommended. Excess addition will damage the hot workability of the steel and cause cracking. With consideration of the costs of addition, the respective upper limits are set to 3.5% for Cr and 2.0% for Mo. Copper makes

the matrix of the steel dense and heightens the strength. Because addition of Cu in a large amount is not favorable from the view points of both the hot workability and the machinability, addition amount should be up to 2.0%. Though nickel also enhances the hardenability like chromium and molybdenum, it is unfavorable element as far as the machinability is concerned. Taking this and the costs of addition into account, the upper limit is set to 4.0%. Boron enhances the hardenability even at a small amount of addition. In order to obtain this effect, boron must be added in an amount of 0.0005% or more. Addition of B exceeding 0.01% is unfavorable due to lowered hot workability.

One or both of Nb: up to 0.2% and V: up to 0.5%

Niobium is useful for preventing coarsening of crystal grains at high temperature. Because the effect of addition saturates as the Nb-content increases, it is recommended to add it in an amount up to 0.2%. Vanadium combines with carbon and nitrogen to form the carbonitride, which makes the crystal grains fine. The effect saturates at a content exceeding 0.5%.

The inclusions existing in the free cutting steel for machine structural use according to the invention are, as shown in Fig. 1, the Ca-containing sulfide inclusion and MnS inclusion. The Ca-containing sulfide inclusion has, according to EPMA analysis, the double structure consisting of the core of oxides of calcium, magnesium, silicon and

aluminum, which are surrounded by MnS containing CaS. In the steel according to the present invention MnS inclusion is finely dispersed. On the other hand, in the conventional free cutting steel, with which just machinability improving effect by MnS is sought, MnS inclusion is, as shown in Fig. 2, of a large form and elongated during rolling of the steel.

The improved chip breakability characterizing the free cutting steel for machine structural use according to the invention is brought about, in one aspect, as mentioned above, by disintegration of the MnS inclusion. On the premise that the amount of the inclusion is constant, disintegration means increase of the number of the inclusion particles. The amount of MnS inclusion in the present steel is determined mainly by S-content, and as the S-content varies in the range of 0.01-0.2% MnS-content also varies with varied number of the fine inclusion particles.

In the present steel the MnS inclusion particles are finer than MnS inclusion particles of the conventional steels. The inclusion particles which give substantial influence on the chip breakability are those having averaged particles size of 1.0 μm or more. The "averaged particle size" means, as defined above, averaged value of the longest diameter and the shortest diameter at the cross section of the particle in the microscopic fields.

Measurement on the numbers of the MnS inclusion particles having averaged particle sizes of 1.0 μm or more per unit area (mm^2) in the steels of the invention exhibiting

excellent chip breakability with different S-contents was made with an optical microscope at a magnitude x400. The numbers of the inclusion particles as shown in TABLE 1 below were obtained and it was ascertained that the relation between the numbers of the inclusion particles and the S-contents is nearly constant. Based on these data it was concluded that the excellent chip breakability can be given by ensuring five or more MnS inclusion particles per mm^2 per S-content 0.01% throughout a wide range of S-content.

TABLE 1 Number of MnS Inclusion Particles in Steel

S-content in the Steel	Number of MnS Inclusion Particles	Number of MnS Inclusion Particles Per S-content 0.01%
0.01%	$5.4/mm^2$	$5.4/mm^2$
0.03%	$16.2/mm^2$	$5.4/mm^2$
0.062%	$32.0/mm^2$	$5.2/mm^2$
0.125%	$32.0/mm^2$	$6.2/mm^2$

The condition that the area percentage of Ca-containing sulfide inclusions containing at least 1.0wt.% of Ca and satisfying the formula (area[μm^2]/aspect ratio)$\geqq$10 occupies 15-40% of the area of all the sulfide inclusion particles:

In order that the inclusion have the above explained double structure it is necessary that the Ca-containing sulfide inclusion contains at least 1.0 wt.% of Ca. From another point of view, the inclusion particles of the Ca-

content of 1.0 wt.% or more (in other words, the content of CaO, which is the typical one of the oxide inclusions, is corresponding to S-content) are useful inclusion and their configuration is the subject of controlling in this invention. The inclusion particles satisfying the formula (area[μm^2]/aspect ratio)≧10 are, in short, relatively large and not so elongated ones.

Significance of the Ca-containing sulfide inclusion particles which are of relatively large size and not so elongated can be seen from the graph of Fig. 3. The graph was prepared by plotting the relation between the aspect ratio and the area occupied by the inclusion particles. The straight inclined line indicates (area[μm^2]/aspect ratio)=10.

Also, significance of the fact that the Ca-containing sulfide inclusion particles containing at least 1.0wt.% of Ca and satisfying the formula (area[μm^2]/aspect ratio)≧10 occupies 15-40% of the area of all the sulfide inclusions for the improved chip breakability can be understood from the graph of Fig. 4. The graph was prepared by plotting the relation between the area percentage of the Ca-containing inclusion particles and the chip breakability indices, which are explained later in reference to the working examples described below, particularly, those of S45C containing 0.045-0.055% of sulfur. Comparison is made with the conventional sulfur free cutting steels containing the same amounts of S. It is seen that tip breakability exceeding that of the conventional steel is obtained in the range of

area percentage of 15-40%.

Based on the interpretation of the above facts from a different point of view it is pointed out that, in case where the area percentage of the Ca-containing sulfide inclusion does not amount to 15%, MnS-component in the inclusion which adheres to and lubricates the surface of the tools will be dominating. Though the melting point of MnS is low, the stability of the lubricating film is so low that the film will not endure and the chip breakability is not improved. On the other hand, at such an excess amount of the Ca-containing inclusion as more than 40%, the relative amount of MnS in all the sulfide inclusions will be low, and it will be difficult to ensure the above mentioned premise that at least five MnS inclusion having averaged particle size of 1.0μm or more exist per S-content 0.01%.

The reason why the present free cutting steel for machine structural use exhibits excellent chip breakability is considered to attribute to the mechanism that, at turning in machining, the sulfide inclusion forms a melted film on the surface of the tool to minimize the curl diameter of the chips. The melted film of the sulfide inclusion exhibits so high lubricating effect that it may be useful for minimizing the curl diameter.

EXAMPLES

The following explained the testing methods carried out in the working examples and the control examples. Measurement of the number of MnS inclusion particles is done as explained above, and the other tests were carried out as noted below.

[Area Percentage of Ca-containing Sulfide Inclusion Particles]

Microscopic photos (magnitude x200) are taken and all the sulfide inclusion particles are classified by EPMA analysis into two, the simple sulfide inclusion and the Ca-containing sulfide inclusion of the double structure. Calculation is made to determine the area percentage occupied by the double structure inclusion particles.

[Lubricating Film]

The test pieces were subjected to machining by turning with cemented carbide tools. Whether the melted inclusion forms a film to cover the surface of the tool and whether the formed film is stable is observed. Also, the chemical composition of the film was determined by EPMA analysis.

[Chip Breakability]

Chips formed by turning under the conditions below were recovered and points "0" to "4" depending on the length of the chips were assigned thereto. The respective sums of the points of each 30 samples were recorded as the "Chip Breakability Index".

Cutting Speed: 150m/min.

Feed: 0.025-0.200mm/rotation

Depth: 0.3-1.0mm

Tool: DNMG150480-MA

The cases where the chip breakability indices of the working examples are superior to those of the conventional sulfur free cutting steels containing the corresponding amounts of sulfur are marked "good", and the cases where the data of the examples are equal or inferior to those of the controls, "no good".

Example 1

The present invention was applied to S45C steels. The prepared steels were cast into ingots, and from the ingots test pieces in the form of round rods of diameter 72mm were taken, and subjected to the tests. The alloy compositions and the test results are shown in TABLE 2 (working examples) and TABLE 3 (control examples).

Example 2

In regard to S15C free cutting steel preparation of the steels and the cutting tests were carried out as done in Example 1. The alloy compositions and the test results are shown in TABLE 4 (working examples) and TABLE 5 (control examples).

Example 3

In regard to S55C free cutting steel preparation of the steels and the cutting tests were carried out as done in

Example 1. The alloy compositions and the test results are shown in TABLE 6 (working examples) and TABLE 7 (control examples).

Example 4

In regard to SCR415 free cutting steel preparation of the steels and the cutting tests were carried out as done in Example 1. The alloy compositions and the test results are shown in TABLE 8 (working examples) and TABLE 9 (control examples).

Example 5

In regard to SCM440 free cutting steel preparation of the steels and the cutting tests were carried out as done in Example 1. The alloy compositions and the test results are shown in TABLE 10 (working examples) and TABLE 11 (control examples).

In the TABLES below the following terms have the following meanings.

Sulfide Area Percentage:

the area in the microscopic fields occupied by the sulfide inclusion particles containing 1 wt.% or more of Ca out of the area of all the sulfide inclusion particles.

Number of MnS Inclusion Particles:

the numbers of MnS inclusion particles having averaged particle sizes of 1.0 μm or more per S-content 0.01% (unit: particles/mm^2).

Film Formation:

observation as to whether film of melted sulfide inclusion is formed to cover the surface of the tools "Yes" indicates formation of sulfide film, "no", formation of oxide film and "-", no film formation.

Chip Breakability:

comparison of the chip breakability indices of the working examples mentioned above with those of the sulfur free cutting steels of the equal S-contents. "Good" means superior results, and "no good", equal or inferior results.

TABLE 2 S45C Series Examples

No.	C	Si	Mn	S	Ca/Mg	Ti/Zr	O	others	Sulfide		Film	Chip
									Area %	Number	Formation	Breakability
1	0.45	0.21	0.65	0.018	Ca:0.0019	Ti:0.0051	0.0012	-	34	5.3	yes	good
2	0.43	0.23	0.81	0.054	Ca:0.0023	Ti:0.0051	0.0032	Cu:0.42	28	7.4	yes	good
3	0.46	0.32	0.93	0.068	Ca:0.0025	Ti:0.0077	0.0043	-	24	8.2	yes	good
4	0.45	0.18	0.71	0.121	Ca:0.0058 Mg:0.0012	Ti:0.0033	0.0052	-	16	9.3	yes	good
5	0.45	0.27	0.84	0.039	Ca:0.0036 Mg:0.0008	Ti:0.0032	0.0012	Te:0.03	38	5.8	yes	good
6	0.44	0.86	0.66	0.044	Ca:0.0023	Ti:0.0045	0.0023	Se:0.051	37	5.3	yes	good
7	0.46	0.19	0.70	0.054	Ca:0.0026	Ti:0.0062	0.0017	-	24	8.2	yes	good
8	0.47	0.25	0.87	0.046	Ca:0.0017	Zr:0.0043	0.0022	-	29	6.7	yes	good
9	0.45	0.20	0.93	0.121	Ca:0.0021	Ti:0.0044	0.0032	REM:0.02	23	5.3	yes	good

TABLE 3 S45C Series Controls

No.	C	Si	Mn	S	Ca/Mg	Ti/Zr	O	others	Sulfide Area %	Sulfide Number	Film Formation	Chip Breakability
1	0.44	0.33	0.73	0.019	Ca:0.0004	Ti:0.0043	0.0031	-	12	4.2	no	no good
2	0.46	0.21	0.84	0.061	Ca:0.0015	Ti:0.0056	0.0019	Cu:0.37	21	3.8	no	no good
3	0.45	0.22	0.88	0.071	Ca:0.0044	Ti:0.0035	0.0043	-	20	4.2	no	no good
4	0.43	0.25	0.75	0.132	Ca:0.0023 Mg:0.0009	Ti:0.0061	0.0009	-	8	6.6	-	no good
5	0.45	0.23	0.80	0.036	Ca:0.0033 Mg:0.0012	Ti:0.0023	0.0025	Te:0.05	45	3.2	yes	no good
6	0.45	0.19	0.91	0.041	Ca:0.0018	Ti:0.0069	0.0031	Se:0.082	47	2.9	yes	no good
7	0.45	0.88	0.63	0.051	Ca:0.0022	Zr:0.0085	0.0067	-	13	3.9	no	no good
8	0.44	0.18	0.88	0.030	Ca:0.0016 Mg:0.0021	Zr:0.0045	0.0023	Te:0.03	51	2.8	no	no good
9	0.47	0.19	0.84	0.051	Ca:0.0022	Ti:0.0041	0.0008	-	14	4.7	yes	no good
10	0.46	0.18	0.89	0.132	Ca:0.0024	Ti:0.0016	0.0012	REM:0.06	12	3.1	yes	no good

TABLE 4 S15C Series Examples

No.	C	Si	Mn	S	Ca/Mg	Ti/Zr	O	others	Sulfide Area %	Sulfide Number	Film Formation	Chip Breakability
1	0.14	0.22	0.51	0.022	Ca:0.0013	Ti:0.0033	0.0014	-	25	6.1	yes	good
2	0.16	0.19	0.59	0.081	Ca:0.0023 Mg:0.0008	Ti:0.0072	0.0033	V:0.08	31	5.6	yes	good
3	0.15	0.31	0.82	0.019	Ca:0.0028	Ti:0.0054 Zr:0.0023	0.0012	B:0.0010	29	6.2	yes	good

TABLE 5 S15C Series Controls

No.	C	Si	Mn	S	Ca/Mg	Ti/Zr	O	others	Sulfide Area %	Sulfide Number	Film Formation	Chip Breakability
1	0.15	0.30	0.60	0.041	Ca:0.0036	Ti:0.0039	0.0035	-	12	6.1	no	no good
2	0.15	0.19	0.99	0.028	Ca:0.0018 Mg:0.0012	Ti:0.0124	0.0022	V:0.08	21	5.6	no	no good
3	0.14	0.24	0.49	0.093	Ca:0.0008	Ti:0.0038 Zr:0.0056	0.0009	B:0.0018	8	6.2	-	no good

TABLE 6 S55C Series Examples

No.	C	Si	Mn	S	Ca/Mg	Ti/Zr	O	others	Sulfide Area %	Sulfide Number	Film Formation	Chip Breakability
1	0.57	0.31	0.91	0.018	Ca:0.0026	Ti:0.0045	0.0038	-	34	5.4	yes	good
2	0.54	0.18	0.87	0.044	Ca:0.0025 Mg:0.0009	Ti:0.0062	0.0025	-	23	7.3	yes	good
3	0.55	0.19	0.88	0.023	Ca:0.0019	Ti:0.0058 Zr:0.0052	0.0017	Ni:1.23	21	7.8	yes	good

TABLE 7 S55C Series Controls

No.	C	Si	Mn	S	Ca/Mg	Ti/Zr	O	others	Sulfide Area %	Sulfide Number	Film Formation	Chip Breakability
1	0.55	0.22	1.04	0.024	Ca:0.0033	Ti:0.0033	0.0046	-	11	4.9	no	no good
2	0.56	0.26	0.89	0.054	Ca:0.0028 Mg:0.0006	Ti:0.0072	0.0013	-	24	4.0	no	no good
3	0.55	0.19	0.94	0.021	Ca:0.0011	Ti:0.0063 Zr:0.0037	0.0011	Ni:2.23	6	5.3	-	no good

TABLE 8 SCR415 Series Examples

No.	C	Si	Mn	S	Ca/Mg	Ti/Zr	O	others	Sulfide Area %	Sulfide Number	Film Formation	Chip Breakability
1	0.17	0.12	0.68	0.036	Ca:0.0022	Ti:0.0053	0.0031	Cr:1.89	34	5.3	yes	good
2	0.15	0.21	0.71	0.048	Ca:0.0027 Mg:0.00079	Ti:0.0045	0.0035	Cr:1.12 Nb:0.039	29	6.0	yes	good
3	0.16	0.15	0.56	0.096	Ca:0.0019	Ti:0.0032 Zr:0.0033	0.0018	Cr:1.54	19	7.7	yes	good

TABLE 9 SCR415C Series Controls

No.	C	Si	Mn	S	Ca/Mg	Ti/Zr	O	others	Sulfide Area %	Sulfide Number	Film Formation	Chip Breakability
1	0.15	0.09	0.73	0.034	Ca:0.0012	Ti:0.0004	0.0046	Cr:1.93	10	4.5	no	no good
2	0.14	0.18	0.81	0.045	Ca:0.0009 Mg:0.0011	Ti:0.0082	0.0028	Cr:1.21 Nb:0.033	12	4.4	no	no good
3	0.16	0.14	0.54	0.089	Ca:0.0022	Ti:0.0029 Zr:0.0025	0.0008	Cr:1.88	11	6.2	-	no good

TABLE 10 SCM440 Series Examples

No.	C	Si	Mn	S	Ca/Mg	Ti/Zr	O	others	Sulfide Area %	Sulfide Number	Film Formation	Chip Breakability
1	0.40	0.24	0.63	0.037	Ca:0.0024	Ti:0.0042	0.0023	Cr:1.25 Mo:0.14	34	5.5	yes	good
2	0.39	0.32	0.53	0.061	Ca:0.0017 Mg:0.0006	Ti:0.0056	0.0041	Cr:2.01 Mo:0.23 Ni:0.23	23	6.5	yes	good
3	0.42	0.19	0.98	0.014	Ca:0.0026	Ti:0.0061 Zr:0.0034	0.0011	Cr:1.45 Mo:0.54	24	6.8	yes	good

TABLE 11 SCM440 Series Controls

No.	C	Si	Mn	S	Ca/Mg	Ti/Zr	O	others	Sulfide Area %	Sulfide Number	Film Formation	Chip Breakability
1	0.44	0.26	0.68	0.041	Ca:0.014	Ti:0.0023	0.0024	Cr:1.32 Mo:0.16	9	4.5	no	no good
2	0.38	0.33	0.49	0.058	Ca:0.0031 Mg:0.0014	Ti:0.0018	0.0039	Cr:1.96 Mo:0.25 Ni:0.34	6	3.8	no	no good
3	0.41	0.21	1.02	0.016	Ca:0.0024	Ti:0.0023 Zr:0.0021	0.0032	Cr:1.88 Mo:0.49	12	4.8	-	no good

Industrial Applicability

The steel for machine structural use having good chip breakability according to the present invention has the same machinability as that of the previously disclosed free cutting steel. Namely, because the present steel also contains the inclusion giving high machinability, i.e., the Ca-containing sulfide inclusion particles of the double structure, at machining, particularly, at turning with cemented carbide tools, the targeted increase of the tool life ratio (the ratio of tool life of the present free cutting steel to the tool life of the conventional sulfur free cutting steel containing equal amounts of sulfur) to five times is easily achieved.

Furthermore, the present invention, by choosing the requisite that the Ca-containing sulfide inclusion particles of the specific configuration is in the range of 15-40% of all the sulfide inclusions, improved the chip breakability so remarkably that the possible entanglement of the chips to the tools and works does not occur, and thus, eliminated the troubles in transfer of the chips on chip conveyers. The bottleneck for automation of machining for manufacturing machine parts was solved by the present invention, and therefore, contribution by the invention to decrease of the manufacturing costs of various machine parts, particularly, parts for automobiles is remarkable.

Brief Explanation of the Drawings

Fig. 1 is a microscopic photo illustrating the structure of the inclusion in the free cutting steel for machine structural use according to the invention;

Fig. 2 is a microscopic photo illustrating the structure of the inclusion in the conventional sulfur free cutting steel;

Fig. 3 is a graph prepared by plotting the relation between the aspect ratio and the area occupied by the Ca-containing sulfide inclusion particles and MnS inclusion particles in the free cutting steels for machine structural use; and

Fig. 4 is a graph prepared by plotting the relation between the area percentage of the Ca-containing sulfide inclusion particles and the chip breakability indices of the free cutting steels for machine structural use.